Implications of the 125 GeV Higgs boson for scalar dark matter and for the CMSSM phenomenology

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ABSTRACT

We study phenomenological implications of the ATLAS and CMS hints of a 125 ± 1 GeV Higgs boson for the singlet, doublet and singlet plus doublet non-supersymmetric dark matter models, and for the phenomenology of the CMSSM. We show that in those scalar dark matter models the vacuum stability bound on Higgs boson mass is lower than in the standard model and the 125 GeV Higgs boson is consistent with the models being valid up the GUT or Planck scale. We perform a detailed study of the full CMSSM parameter space keeping the Higgs boson mass fixed to 125 ± 1 GeV, and study in detail the freeze-out processes that imply the observed amount of dark matter. After imposing all phenomenological constraints except for the muon $(g-2)_\mu$, we show that the CMSSM parameter space is divided into well separated regions with distinctive but in general heavy sparticle mass spectra. Imposing the $(g-2)_\mu$ constraint introduces severe tension between the high SUSY scale and the experimental measurements – only the slepton co-annihilation region survives with potentially testable sparticle masses at the LHC. In the latter case the spin-independent DM-nucleon scattering cross section is predicted to be below detectable limit at the XENON100 but might be of measurable magnitude in the general case of light dark matter with large bino-higgsino mixing and unobservably large scalar masses.

December 2011

1 Introduction

In the standard model (SM) of particle interactions the only unknown quantity is the Higgs boson mass [1]. Any assumption that fixes the Higgs boson quartic self-coupling at any scale Λ implies a prediction for the Higgs boson mass. Many models of that sort have been proposed in the past based on different arguments of new physics beyond the SM. In general, the properties of the SM Higgs potential are among the best studied quantities in particle physics [2].

Based on the 4.7 fb^{-1} data collected in 2011, the CMS [3] experiment excludes the SM Higgs boson mass above 128 GeV at 99% C.L. In addition, both the ATLAS [4] and the CMS [3] experiments have reported a signal excess for the SM-like Higgs boson at mass $M_H = 125 \pm 1$ GeV with global significances of 2.5σ and 1.9σ, respectively. The corresponding local significances without taking into account the look-elsewhere-effect (LEE) are 3.6σ and 2.6σ, respectively. Although those hints may turn out to be statistical fluctuations as happened in the case of the "142 GeV excess" in the 1 fb^{-1} LHC data presented at EPS2011, this time both experiments are consistent with each other as well as with the SM expectations for the signal significance.

If the present experimental hint for $M_H \approx 125$ GeV Higgs boson is confirmed next year, this result will have a profound impact on physics. In the context of the SM, this mass is below the vacuum stability bound $M_H > 128$ GeV for SM to be valid up to the scale of gauge coupling unification $\Lambda_{\rm GUT}$. Vanishing SM Higgs boson self-coupling $\lambda(\Lambda) = 0$ below the GUT scale, $\Lambda < \Lambda_{\rm GUT}$, implies that the fundamental scale of new physics related to the Higgs and, perhaps, flavour generation, might be lower than the GUT scale. On the other hand, this Higgs boson mass may imply that there is new physics beyond the SM not too far from the electroweak scale that modifies the Higgs boson mass prediction. The most popular such a framework is low energy supersymmetry (SUSY) that prefers a light Higgs boson. For SUSY scenarios, however, the lightest Higgs boson mass $M_H \approx 125$ GeV is unusually high, close to the upper bound in popular SUSY models, and implies a larger SUSY scale than one expects from naturalness arguments. Clearly those arguments imply that the present hint for the Higgs boson mass requires re-assessment of several "standard" concepts both in SUSY and in non-SUSY models.

Any realistic model of new physics beyond the SM must explain the existence of dark matter (DM) of the Universe and, perhaps, address the issue of the Higgs hierarchy problem. The aim of this work is twofold. First, assuming that the Higgs boson mass is in the range $M_H = 125 \pm 1$ GeV, we study the implications of this assumption on the vacuum stability in scalar DM models. In those models the DM and Higgs sectors are related via the Higgs portal and the scalar potentials are in general rather complicated. Due to many new self-interactions in the scalar sector, the SM Higgs quartic coupling renormalization is modified and one might expect that the triviality $\lambda(\Lambda) = 0$ may be achieved for any Λ. We show that this is indeed the case and the SM vacuum stability results will be changed in the non-SUSY scalar DM models compared to the SM predictions. In particular, we show that the 125 GeV Higgs boson is consistent with the vacuum stability for $\Lambda > \Lambda_{\rm GUT}$ and, therefore, those models do not require new scales below the GUT scale.

Second, a technically much more involved question is what is the implication of the $M_H = 125\pm$

1 GeV assumption for DM generation, DM direct detection and for the LHC phenomenology in SUSY models. Generically such a heavy Higgs boson requires rather heavy stops, *i.e.*, a large SUSY breaking scale[1]. This, in general, implies a large fine tuning to obtain the correct electroweak scale, very fine tuned DM annihilation channels and poor prospects for discovering SUSY at the LHC. We analyze those issues in detail in the constrained minimal supersymmetric standard model (CMSSM) and show that $M_H = 125 \pm 1$ GeV and the correct DM relic abundance together select out parameter regions with well defined sparticle spectra and predictions for DM direct detection in experiments like the XENON100. If, in addition, also the muon anomalous magnetic moment $(g-2)_\mu$ constraint is imposed, only a tiny parameter region is singled out in the CMSSM that induces DM via the slepton co-annihilation channel. In this parameter space the LHC has a real chance to observe gluinos and the lightest stop but the XENON100 is predicted to obtain null result. In the other cases that also predict the observed amount of DM the result might be opposite – only TeV scale DM is observed in DM direct detection experiments while the heavy scalars decouple from the spectrum. We classify those possibilities and discuss their phenomenology.

In section 2 we present results for models of the SM extended with scalars: a complex $SU(2)$ singlet, an inert doublet or both. In section 3 we give scans for CMSSM with both with and without the $(g-2)_\mu$ constraint. We conclude in section 4.

2 Scalar dark matter and vanishing Higgs self-coupling

Triviality of the SM Higgs boson self-coupling, $\lambda = 0$, at some scale Λ is an interesting possibility. From the theoretical point of view this may indicate a scale where some new fundamental theory beyond the SM generates the Higgs boson and its Yukawa couplings, *i.e.*, flavour. From the phenomenological point of view this scale uniquely predicts the Higgs boson mass due to the evolution of the Higgs self-coupling via renormalization group equations. Examples of this running at two loop level in the SM are presented in Fig. 1 for different values of the SM Higgs boson masses as indicated in the figure. Our results agree with the recent works [2]. This result shows that the LHC indications for the Higgs boson imply the triviality scale to be about 10^{10} GeV rather than the GUT scale 2.1×10^{16} GeV. Such a low scale can be associated with the seesaw scale [6] where neutrino masses are generated rather than with the GUT scale.

The natural question to ask is that what happens to the vacuum stability in models with extended scalar sector? Particularly interesting among those models are the scalar DM models that have been already addressed in the 125 GeV Higgs boson scenario [7][2].

[1]In the context of the 125 GeV Higgs boson this point has already been noted in [5].

[2]Singlet fermion DM has also been studied [8].

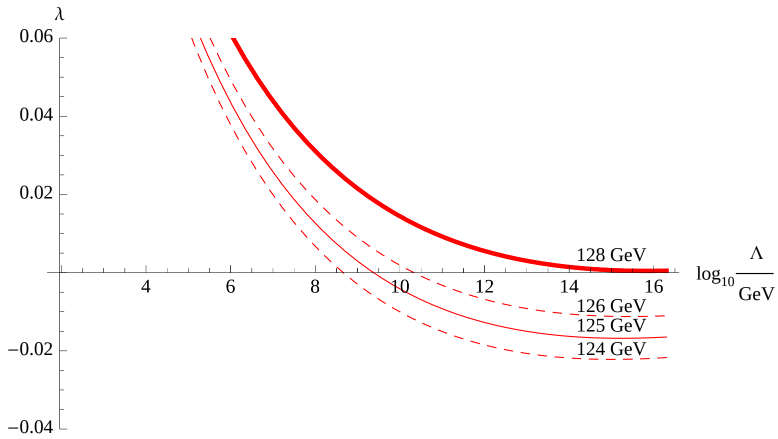

Figure 1: *Running of the SM Higgs boson self-coupling λ for different Higgs boson masses at two loop level.*

2.1 Scalar singlet model

The simplest DM model is obtained by extending the SM scalar potential with a real [9] or complex [10] singlet scalar field. In view of embedding this scenario into a GUT framework [11], we study the complex singlet scalar $S = (S_H + iS_A)/\sqrt{2}$, but the phenomenology in the real singlet case is similar. The vacuum stability of the real singlet model has previously been studied in [12].

Denoting the SM Higgs boson with H_1, the most general Lagrangian invariant under the Z_2 transformations $H_1 \to H_1$, $S \to -S$ is given by

$$\begin{aligned} V = {}& \mu_1^2 H_1^\dagger H_1 + \lambda_1 (H_1^\dagger H_1)^2 + \mu_S^2 S^\dagger S + \frac{\mu_S'^2}{2}\left[S^2 + (S^\dagger)^2\right] + \lambda_S (S^\dagger S)^2 + \frac{\lambda_S'}{2}\left[S^4 + (S^\dagger)^4\right] \\ &+ \frac{\lambda_S''}{2}(S^\dagger S)\left[S^2 + (S^\dagger)^2\right] + \lambda_{S1}(S^\dagger S)(H_1^\dagger H_1) + \frac{\lambda_{S1}'}{2}(H_1^\dagger H_1)\left[S^2 + (S^\dagger)^2\right]. \end{aligned} \tag{1}$$

The vacuum stability conditions for the complex singlet model with a global $U(1)$ are given in [10]. However, those conditions are not applicable here because this model is far too simple compared to the general case (1). For the general model the full vacuum stability conditions are rather complicated and have been addressed previously in Ref. [13]. However, the conditions of [13] turn out to be too restrictive because they are derived by requiring the matrix of quartic couplings to be positive. This is required only if the coefficients of biquadratic terms are negative and, in general, cut out some allowed parameter space.

The conditions arising from pure quartic terms of the potential (1) are

$$\lambda_1 \geq 0, \quad \lambda_S + \lambda_S' \geq |\lambda_S''|. \tag{2}$$

For simplicity we consider in addition only the case when the coefficents of the terms biquadratic in real fields (*e.g.* the coefficient of $S_H^2 S_A^2$) are all non-negative, giving

$$\lambda_S - 3\lambda_S' \geq 0, \quad \lambda_{S1} - |\lambda_{S1}'| \geq 0. \tag{3}$$

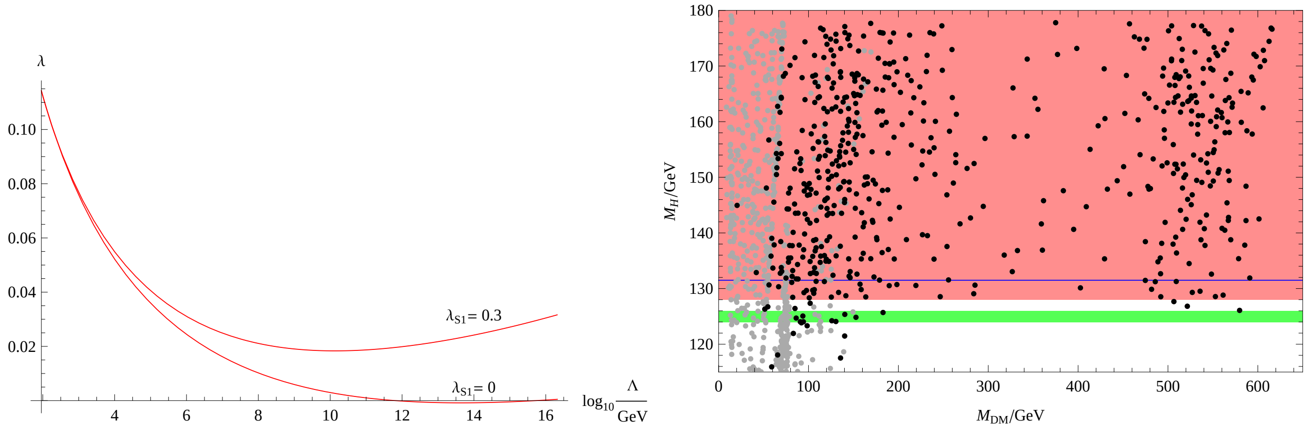

Figure 2: *Left: Running of the Higgs self-coupling in the complex singlet model for two different values of* λ_{S1}*. Right: Scatter plot of the Higgs boson mass predictions in the singlet plus doublet DM model at one loop level. The blue line shows the SM one loop vacuum stability bound* $M_H > 131.5$ GeV *for a fixed* $\Lambda_{\text{GUT}} = 2.1 \times 10^{16}$ GeV*. The light red area is excluded by the CMS, the green area shows* 125 ± 1 GeV*. Gray points are excluded by the XENON100 bound, black points satisfy the XENON100 bound.*

Doing this, we exclude a part of the points that would be allowed by the full vacuum stability conditions. However, this is sufficient for our purposes because our aim is to show that regions of the parameter space exist that lower the SM Higgs boson mass vacuum stability bound.

The one-loop RGEs can be obtained from those in [13] by setting all couplings of the inert doublet to zero. The RGEs show that nonzero λ_{S1} or λ'_{S1} give a positive contribution to the β-function of λ_1, pushing the scale where $\lambda_1 \equiv \lambda = 0$ higher. For qualitative understanding of the model, we let $\lambda_S = \lambda'_S = \lambda''_S = \lambda'_{S1} = 0$. Fig. 2 shows one loop level running for the 125 GeV Higgs quartic coupling for $\lambda_{S1} = 0$ (the SM case) and for $\lambda_{S1} = 0.3$. In the latter case, the minimum bound on Higgs boson mass from the vacuum stability argument is lowered and the vacuum can be stable up to the GUT or Planck scale.

2.2 Inert doublet model

In the inert doublet model [14] there is, besides the SM Higgs H_1, an additional scalar doublet H_2 that is odd under a new Z_2 symmetry and thus does not have Yukawa couplings. The neutral component of the inert doublet is a DM candidate. The most general Lagrangian invariant under the Z_2 transformations $H_1 \to H_1$, $H_2 \to -H_2$ is

$$\begin{aligned} V =& \mu_1^2|H_1|^2 + \mu_2^2|H_2^2| + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 \\ &+ \lambda_4|H_1^\dagger H_2|^2 + \frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + \text{h.c.}\right] . \end{aligned} \tag{4}$$

The requirement of vacuum stability imposes

$$\lambda_1, \lambda_2 > 0\,, \qquad \lambda_3, \lambda_3 + \lambda_4 - |\lambda_5| > -2\sqrt{\lambda_1\lambda_2}\,. \tag{5}$$

We will not perform a detailed study of the inert doublet model alone here, because it is a limiting case of the singlet plus doublet model studied below.

2.3 Singlet plus doublet model

This model has been previously studied in the context of $SO(10)$ GUT [11, 13, 15, 16, 17]. Here, however, we present a general scan of parameters without imposing any GUT boundary conditions.

The Lagrangian with Z_2 even H_1 and odd H_2 and S is

$$\begin{aligned}
V = {}& \mu_1^2 H_1^\dagger H_1 + \lambda_1 (H_1^\dagger H_1)^2 + \mu_2^2 H_2^\dagger H_2 + \lambda_2 (H_2^\dagger H_2)^2 \\
&+ \mu_S^2 S^\dagger S + \frac{\mu_S'^2}{2}\left[S^2 + (S^\dagger)^2\right] + \lambda_S (S^\dagger S)^2 + \frac{\lambda_S'}{2}\left[S^4 + (S^\dagger)^4\right] + \frac{\lambda_S''}{2}(S^\dagger S)\left[S^2 + (S^\dagger)^2\right] \\
&+ \lambda_{S1}(S^\dagger S)(H_1^\dagger H_1) + \lambda_{S2}(S^\dagger S)(H_2^\dagger H_2) \\
&+ \frac{\lambda_{S1}'}{2}(H_1^\dagger H_1)\left[S^2 + (S^\dagger)^2\right] + \frac{\lambda_{S2}'}{2}(H_2^\dagger H_2)\left[S^2 + (S^\dagger)^2\right] \\
&+ \lambda_3 (H_1^\dagger H_1)(H_2^\dagger H_2) + \lambda_4 (H_1^\dagger H_2)(H_2^\dagger H_1) + \frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + (H_2^\dagger H_1)^2\right] \\
&+ \frac{\mu_{SH}}{2}\left[S^\dagger H_1^\dagger H_2 + H_2^\dagger H_1 S\right] + \frac{\mu_{SH}'}{2}\left[S H_1^\dagger H_2 + H_2^\dagger H_1 S^\dagger\right].
\end{aligned} \tag{6}$$

Just as for the complex singlet model, we consider here only the case of positive biquadratic terms for real fields (with the exception of the purely inert doublet conditions that are completely general). The simplified vacuum stability conditions for this model are given by (2), (3) and (5) together with an additional constraint[3]

$$\lambda_{S2} - |\lambda_{S2}'| \geq 0. \tag{7}$$

The RGE-s for couplings and mass parameters are given in [13]. We have performed a scan of the parameters for the values of couplings randomly generated in the ranges 115 GeV $\leq M_H \leq$ 180 GeV, 10 GeV $\leq \mu_S \leq 10^3$ GeV, 10 GeV $\leq \mu_2 \leq 10^3$ GeV, 10 GeV$^2 \leq \mu_S'^2 \leq 100$ GeV^2, 10^{-2} GeV $\leq |\mu_{SH}'| \leq 10^3$ GeV, $0 \leq \lambda_2 \leq 0.1$, $0 \leq \lambda_S \leq 0.1$, $-0.1 \leq \lambda_S' \leq 0.1$, $-1 \leq \lambda_3 \leq 1$, $-1 \leq \lambda_4 \leq 1$, $-1 \leq \lambda_{S1} \leq 1$, $-1 \leq \lambda_{S2} \leq 1$, with the rest of the parameters set to zero. In the case of every generated point we check that it satisfies the requirements of vacuum stability and perturbativity in the whole range from M_Z to $\Lambda_{\rm GUT}$, positivity of masses at M_Z and lie within

[3] Again, similarly to the singlet model the constraints in Ref. [13] that were used in the previous version of the current paper are too restrictive.

the 3σ range of the WMAP cosmic abundance. The points that satisfy all the constraints are shown in the right panel of Fig. 2.

In Fig. 2, the region excluded by the CMS is shown in red; the $124 - 126$ GeV Higgs mass range is shown in green. Because the points were calculated using one-loop RGEs for the doublet plus singlet model, we show the GUT scale vacuum stability bound for the SM at one-loop level with the blue line (the two-loop bound is lower by about 3.5 GeV). The points excluded by the XENON100 experiment [18] are shown in gray while the black points satisfy the present direct detection constraints.

As seen in the figure, there are points that can give vacuum stability up to the GUT scale with a low mass Higgs. Thus we conclude that the scalar DM models are perfectly consistent with the 125 GeV higgs mass and do not require the existence of new fundamental scale below the GUT or Planck scale.

3 CMSSM dark matter and LHC phenomenology for the 125 GeV Higgs boson

The CMSSM is the most thoroughly studied SUSY model. Naturally, if the Higgs boson is discovered with the mass $M_H = 125 \pm 1$ GeV, one would like to know what is the implication of this discovery for the phenomenology of this model. Here we show that if all the phenomenological constraints are taken into account, the CMSSM parameter space shrinks into well defined small regions according to the dominant DM freeze-out process. We study whether the CMSSM can be tested at the LHC and in DM direct detection experiments such as XENON100 and conclude that, despite of heavy Higgs boson, discovery of CMSSM gluinos and/or stops is not excluded at the LHC. In addition, if the sparticle spectrum is too heavy for the LHC discovery, DM direct detection experiments may still discover the CMSSM DM.

It is well known that such a heavy Higgs boson imposes challenges on SUSY models in which the Higgs boson mass is predicted to be

$$M_H^2 = M_Z^2 \cos^2 2\beta + \delta_t^2, \tag{8}$$

where δ_t is the stop dominated loop contribution. For $M_H \approx 125$ GeV the loop contribution must be as large as the tree level one which requires very heavy stops unless there is extremely large trilinear scalar coupling that makes the lightest stop light due to large mixing. A heavy SUSY scale, in turn, makes the lightness of electroweak symmetry breaking scale unnatural. In addition, a heavy sparticle spectrum imposes fine tunings on the processes that contribute to the DM freeze-out in SUSY models. Taking those facts into account, the phenomenological constraints that are commonly addressed in the context of SUSY models, summarized in Table 1, the constraints from SUSY searches at the LHC and the constraints from DM direct detection, the CMSSM parameter space is known to be rather fine tuned [19, 20, 21, 22, 23].

quantity	experiment	Standard Model
$\alpha_3(M_Z)$ [25]	0.1184 ± 0.0007	parameter
m_t [26]	173.2 ± 0.9	parameter
m_b [27]	4.19 ± 0.12	parameter
$\Omega_{\rm DM}h^2$ [28]	0.112 ± 0.0056	0
δa_μ [29]	$(2.8 \pm 0.8) \times 10^{-9}$	0
$\text{BR}(B_d \to X_s\gamma)$ [30]	$(3.50 \pm 0.17) \times 10^{-4}$	$(3.15 \pm 0.23)\, 10^{-4}$
$\text{BR}(B_s \to \mu^+\mu^-)$ [31]	$< 1.1 \times 10^{-8}$ at 95%C.L.	$(0.33 \pm 0.03)\, 10^{-8}$
$\text{BR}(B_u \to \tau\bar{\nu})/\text{SM}$ [32]	1.25 ± 0.40	1

Table 1: *Used constraints for the CMSSM analyses.*

At the GUT scale the parameter space of the CMSSM is described by five parameters,

$$m_0,\ M_{1/2},\ A_0,\ \tan\beta,\ \text{sign}(\mu), \tag{9}$$

the common scalar mass, the common gaugino mass, the common trilinear coupling, ratio of two Higgs vevs and the sign of the higgsino mass parameter. To scan over the CMSSM parameter space we randomly generate the parameters in the following ranges: $300 < m_0,\ M_{1/2} < 10000$ GeV, $|A_0| < 5m_0$, $3 < \tan\beta < 60$, $\text{sign}(\mu) = \pm$. We use the MicrOMEGAs package [24] to compute the electroweak scale sparticle mass spectrum, the Higgs boson masses, the DM relic abundance $\Omega_{\rm DM}$, the spin-independent DM-nucleon direct detection cross section $\sigma_{\rm SI}$ and the other observables in Table 1. In addition, we require $M_H = 125 \pm 1$ GeV. We do not attempt to find the best fit regions of the parameter space because there is no Higgs mass measurement yet. In addition, there is a few GeV theoretical uncertainty in the computation of SUSY Higgs masses in the available codes. Therefore, to select the phenomenologically acceptable parameter space we impose 3σ hard cuts for the observables in Table 1. Our approach should be regarded as an example study of the CMSSM parameter space for heavy Higgs boson; qualitatively similar results should hold if the real Higgs boson mass deviates from 125 GeV by a few GeV.

Our results are presented in Figs. 3-6. Because there is a tension between the observables that push the SUSY scale to high values and the measurement of $(g-2)_\mu$ [19], we disregard the $(g-2)_\mu$ constraint for the moment. The reason is that the CMSSM parameter fit is largely dominated by two observables, the DM relic abundance and the $(g-2)_\mu$, the latter constraining mostly the scale. We would first like to study the parameter space that induces correct M_H and $\Omega_{\rm DM}$. Therefore we discuss the implications of the $(g-2)_\mu$ constraint later.

In Fig. 3 we present our results in scatter plots without the $(g-2)_\mu$ constraint. In the upper left panel the results are presented in $(m_0, M_{1/2})$ plane, in the upper right panel in $(M_{\rm DM}, \sigma_{\rm SI})$ plane, in the lower left panel in $(M_{\rm DM}, M_{\tilde{\chi}_1^+} - M_{\rm DM})$ plane, and in the lower right panel in $(M_{\rm DM}, M_{\tilde{t}_1} - M_{\rm DM})$ plane. The first 100 days XENON100 constraint [18] is also shown.

We identify five distinctive parameter regions according the dominant DM annihilation processes.

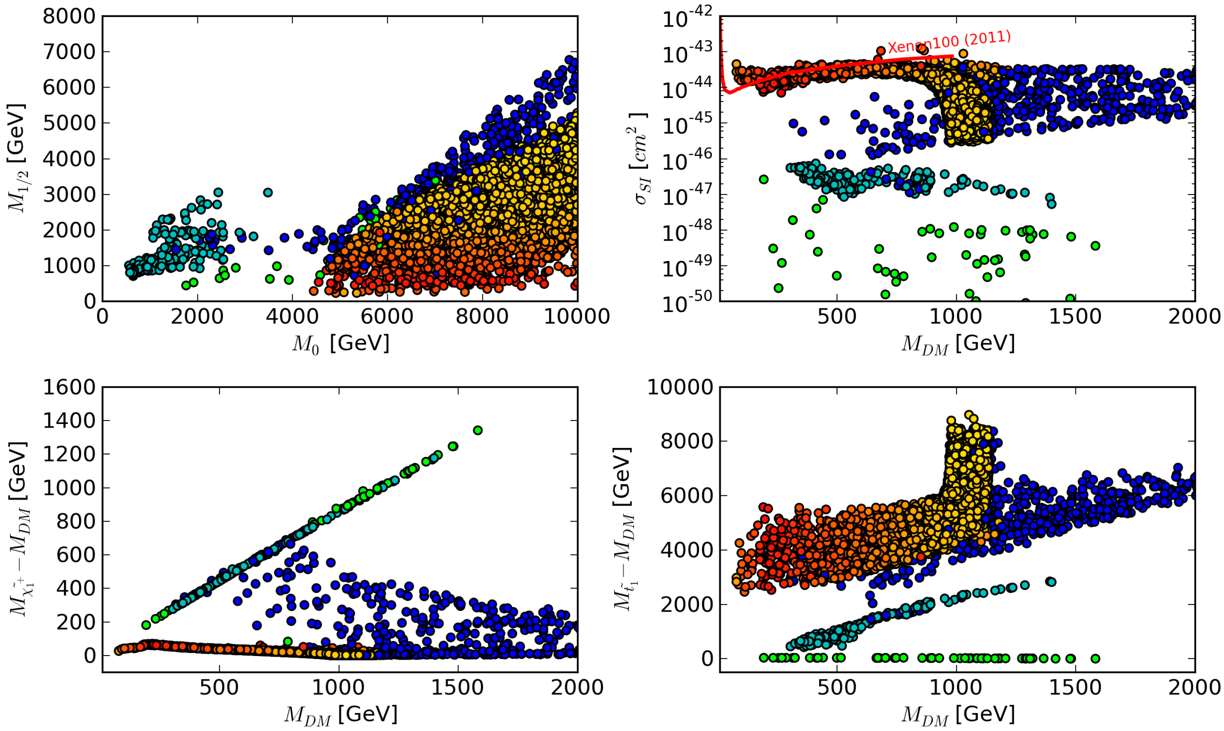

Figure 3: *Scatter plots over the CMSSM parameter space keeping $M_H = 125 \pm 1$ GeV. Colours represent different dominant DM freeze-out processes. Light blue: slepton co-annihilation; green: stop co-annihilation; red to orange: well-tempered neutralino, yellow: higgsino; dark blue: heavy Higgs resonances. No $(g-2)_\mu$ constraint is imposed.*

- The light blue points with small m_0 and $M_{1/2}$ represent the slepton co-annihilation region. They are featured by very large values of $\tan\beta$. Those points represent the best fit value of the CMSSM [19] and have low enough sparticle masses that allow potential SUSY discovery at the LHC. However, their spin-independent direct detection cross section is predicted to be below 10^{-46} cm^2 and remains unobservable at the XENON100. The present XENON100 experimental bound is plotted in the upper right panel with solid red line. This is the only parameter region that survives at 3σ level after the $(g-2)_\mu$ constraint is imposed.

- The green dots represent the stop co-annihilation region. Consequently those points have the lowest possible stop mass and, due to the mass degeneracy with DM, stops can be long lived and seen as stable very slow particles (R-hadrons) at the LHC. The feature of those points is an enormous trilinear coupling and very large mixing. In addition, the gluino mass can be reachable at the LHC. Their spin-independent direct detection cross section is, unfortunately, unobservable.

- The dots represented by continuous colour code from red to orange represent the so called

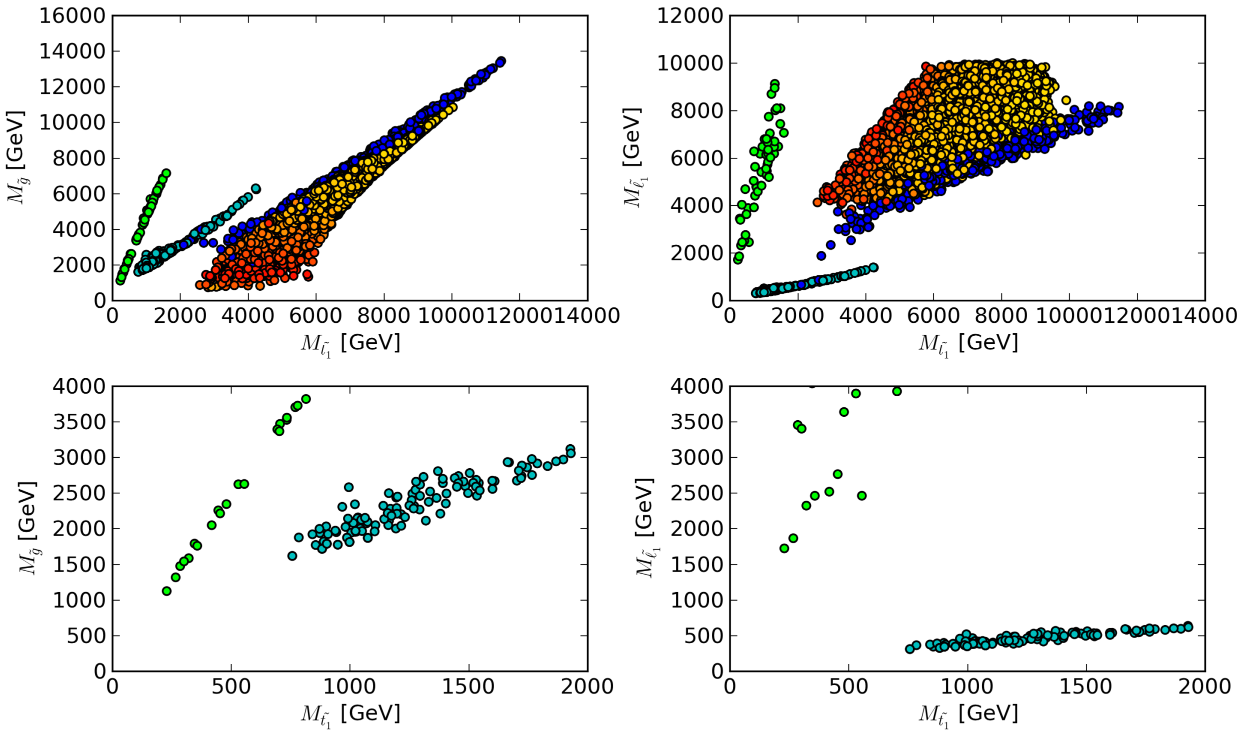

Figure 4: *The same as in Fig. 3 but for physical gluino and the lightest stop and slepton masses. The lower panels present low mass zoom to the upper panels.*

well-tempered neutralino, *i.e.*, neutralinos with large bino-higgsino mixing. The colour varies according to the higgsino component from red (predominantly bino) to yellow (pure higgsino). Therefore those points can simultaneously have small DM mass and large DM-nucleon scattering cross section that can be well tested at the XENON100. However, apart from the DM, all other sparticle masses are predicted to too heavy to be directly produced at the LHC.

- The yellow dots around $M_{\rm DM} \sim 1$ TeV represent the pure higgsino DM that is almost degenerate in mass with chargino. The sparticle mass spectrum is predicted to be even heavier than in the previous case because the DM scale is fixed to be high. These points represent the most general and most abundant bulk of the $M_H = 125$ GeV Higgs scenario – apart from the light DM and heavy Higgs boson there are no other observable consequences because stops can completely decouple. In our case the 10 TeV bound on stops is imposed only because we did not generate larger values of m_0.

- The dark blue points represent heavy Higgs resonances. Those points are featured by very large values of $\tan\beta$ and give the heaviest mass spectrum. In essence those points are just smeared out higgsino points due to additional Higgs-mediated processes.

In order to study the testability of those parameter regions at the LHC we plot in Fig. 4 the

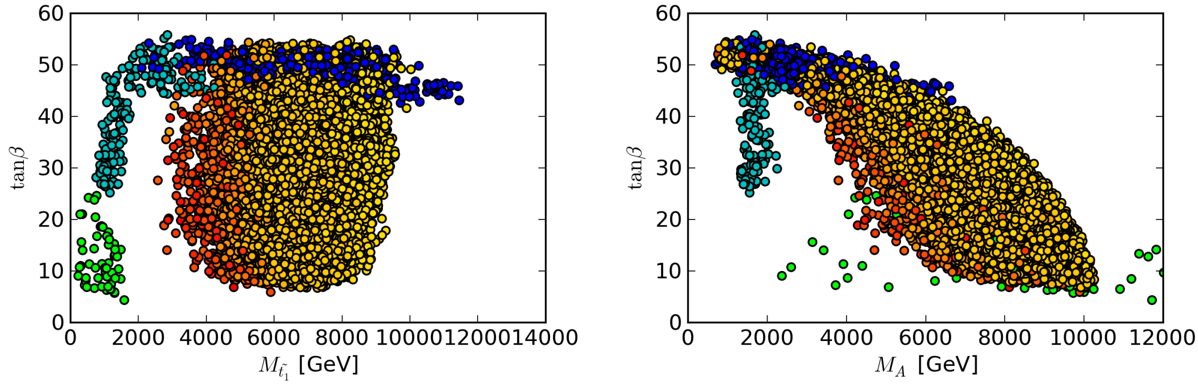

Figure 5: *The same as in Fig. 3 but in* $(M_{\tilde{t}_1}, \tan\beta)$ *and* $(M_A, \tan\beta)$ *planes.*

physical gluino mass against the lightest stop mass and the lightest slepton mass against the lightest stop mass. Clearly, the only two regions of interest for the LHC are the slepton and stop co-annihilation regions. Therefore we plot in lower panels the low mass scale zoom of the upper panels. According to Ref. [33] both regions have a chance to be discovered already in the 7 TeV LHC. Interestingly, due to the stop mass degeneracy with DM the stops can be long-lived. In this case one must search for R-hadrons at the LHC experiments.

To study the $\tan\beta$ and heavy Higgs mass dependence of the generated parameter space we plot in Fig. 5 scatter plots in $(m_{\tilde{t}_1}, \tan\beta)$ and $(M_A, \tan\beta)$ plains. The slepton co-annihilation points have a preferably large $\tan\beta$ that implies large contributions to the observables like $B_s \to \mu\mu$ and the $(g-2)_\mu$. Those allow for indirect testing of this parameter region. Unfortunately the heavy Higgses are predicted to be too heavy to detect at the LHC.

We remind that so far we have disregarded the $(g-2)_\mu$ constraint. If we impose a hard 3σ cut on the generated parameter space, only the slepton co-annihilation region survives. The result is plotted in Fig. 6 where we repeat the content of Fig. 3 but with the additional $(g-2)_\mu$ constraint. As expected, the observed deviation in the $(g-2)_\mu$ from the SM prediction is hard to explain in SUSY models with heavy spectrum. Therefore the two measurements, $(g-2)_\mu$ and $M_H = 125$ GeV, are in conflict in the CMSSM. The conflict is mildest in the slepton co-annihilation case because of large $\tan\beta$ and the lightest sparticle spectrum. Therefore, for the $M_H = 125$ GeV Higgs boson, we predict definite sparticle masses and correlations between them, shown in Fig. 6, for the LHC. If the CMSSM is realized in Nature and if it contributes significantly to the $(g-2)_\mu$, the sparticle spectrum is essentially fixed and potentially observable at the LHC.

4 Conclusions

In this paper we analyzed the implications of the $M_H \approx 125$ GeV Higgs boson for the vacuum stability in scalar DM models and for the phenomenology of CMSSM. This value of the Higgs boson mass is interesting in both cases because it does not fit to the standard expectation

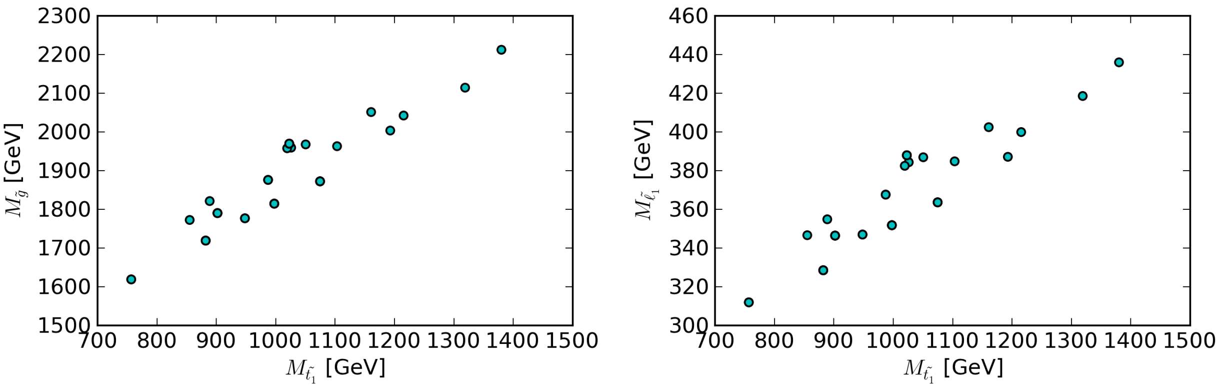

Figure 6: *The same as in Fig. 4 in the case of imposing* 3σ *constraint on the* $(g-2)_\mu$ *prediction.*

neither in the SM nor in SUSY models with SUSY scale below 1 TeV.

We have shown that in the case of non-SUSY scalar DM models the vacuum can be stable up to the GUT scale even for Higgs boson masses much below the corresponding SM bound. Therefore, unlike the SM, for the $M_H \approx 125$ GeV Higgs boson the scalar DM models can be good models up to the GUT or Planck scales.

In SUSY models, to the contrary, the $M_H \approx 125$ GeV Higgs boson is heavier than expected in models that address the naturalness of the electroweak scale. In order to generate such a large Higgs mass at loop level, the SUSY scale must be rather high and could be unobservable at the LHC. This problem can be overcome with extremely large stop A-term so that there is large stop mixing and the lightest of them is light. At the same time the DM neutralino can also be light, either because of slepton co-annihilation or because of large bino-higgsino mixing. In the latter case the DM-nucleon scattering cross section can be observable in direct detection experiments like the XENON100.

To demonstrate those general considerations we studied the CMSSM by scanning over its parameter space and allowing the sparticle mass parameters to be very large. We first considered the case without attempting to explain the $(g-2)_\mu$ in the context of CMSSM. Indeed, we confirmed that for very large A-terms there exists a stop co-annihilation region where all DM, stop and gluino are preferably light. Due to the mass degeneracy between stop and DM the stops can be long lived resulting in non-trivial LHC phenomenology. The second parameter region that is potentially testable at the LHC is the slepton co-annihilation region. However, in general the $M_H \approx 125$ GeV Higgs boson implies very heavy sparticle masses. The exception is, of course, the DM that can be light due to bino-higgsino mixing even if other sparticles are as heavy as 10 TeV. In this case the CMSSM cannot be tested at the LHC but there still is a chance to see the DM scattering off nuclei in the XENON100. If, however, one attempts to explain also the $(g-2)_\mu$ in this framework, there is immediate tension between the high SUSY scale and the large value of the needed $(g-2)_\mu$ contribution. We found that imposing the $(g-2)_\mu$ constraint, only the slepton co-annihilation region survived at 3σ level. This implies

that the CMSSM has definite predictions of the sparticle masses and spectrum to be tested at the LHC experiments.

Acknowledgements
We thank A. Strumia for several discussions. This work was supported by the ESF grants 8090, 8499, 8943, MTT59, MTT60, MJD140, JD164, by the recurrent financing SF0690030s09 project and by the European Union through the European Regional Development Fund.

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